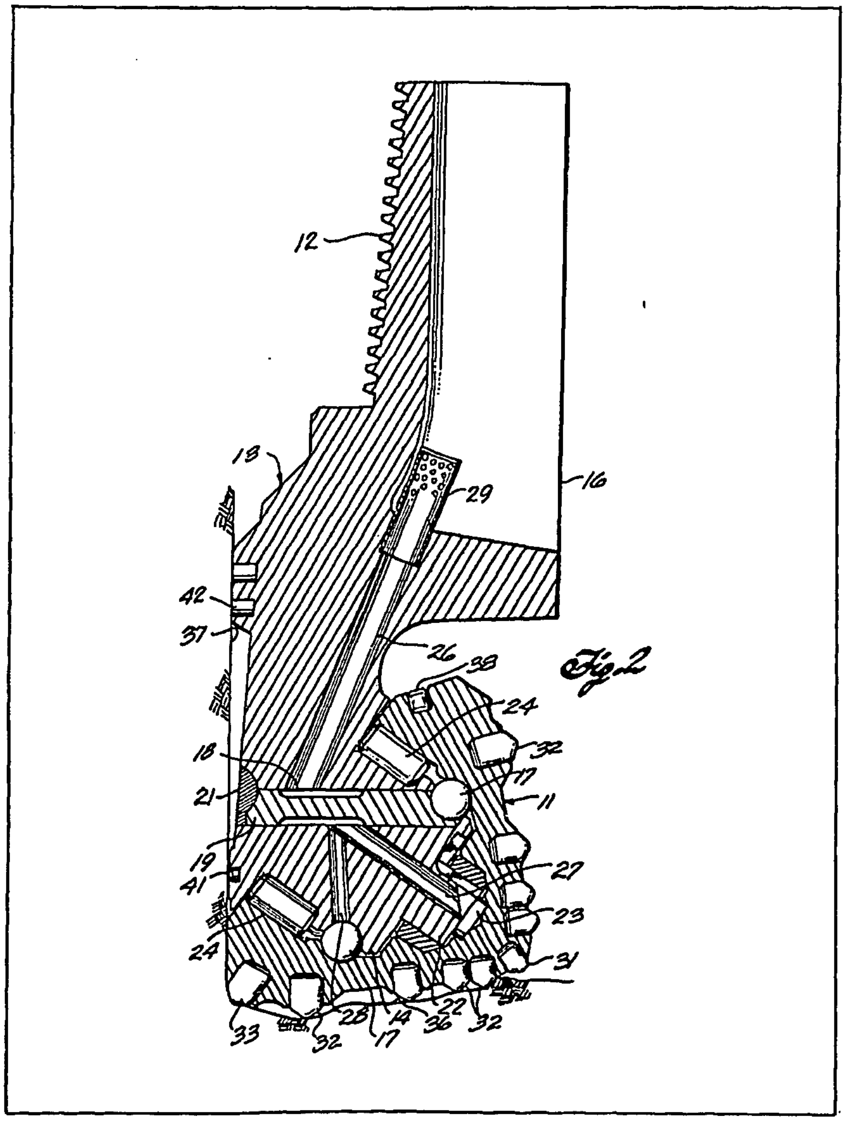
(12) UK Patent Application (19) GB (11) 2 064 619 A

(21) Application No 7930990
(22) Date of filing 6 Sep 1979
(43) Application published 17 Jun 1981
(51) INT CL[3] E21B 10/52
(52) Domestic classification E1F 103 GB
(56) Documents cited GB 1515532
(58) Field of search E1F

(71) Applicants
Smith International, Inc., 4343 Von Karman Avenue, Newport Beach, California 92660, United States of America
(72) Inventor
Donald James Derthick
(74) Agents
Graham Watt & Co., Riverhead, Sevenoaks, Kent TN13 2BN

(54) Rock bit and drilling method using same

(57) An earth boring rock bit comprises a bit body and a plurality of rolling cone cutters (11) mounted on the bit body, the rolling cone cutters each comprising a plurality of tungsten carbide inserts including a plurality of gage inserts (33) for drilling adjacent the peripheral wall of the hole being drilled. The gage inserts (33) on each rolling cone cutter are formed of primarily tungsten carbide particles sintered with a matrix of nickel in the range of from about 3 to 20% by weight of the composite and preferably in the range of from about 6 to 16% by weight. If desired the gage row of inserts can be formed with up to about 1/3 by weight tantalum carbide substituting for a portion of the tungsten carbide. Such a rock bit is particularly useful for drilling geothermal wells where the gage inserts are subjected to high temperatures and severe erosion and corrosion.



GB 2 064 619 A

BEST AVAILABLE COPY

2064619
1/1

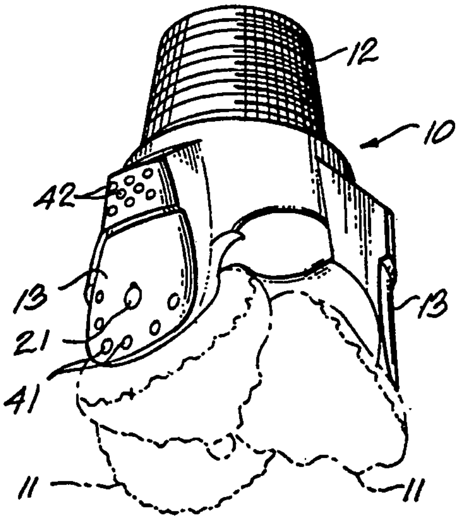


Fig. 1

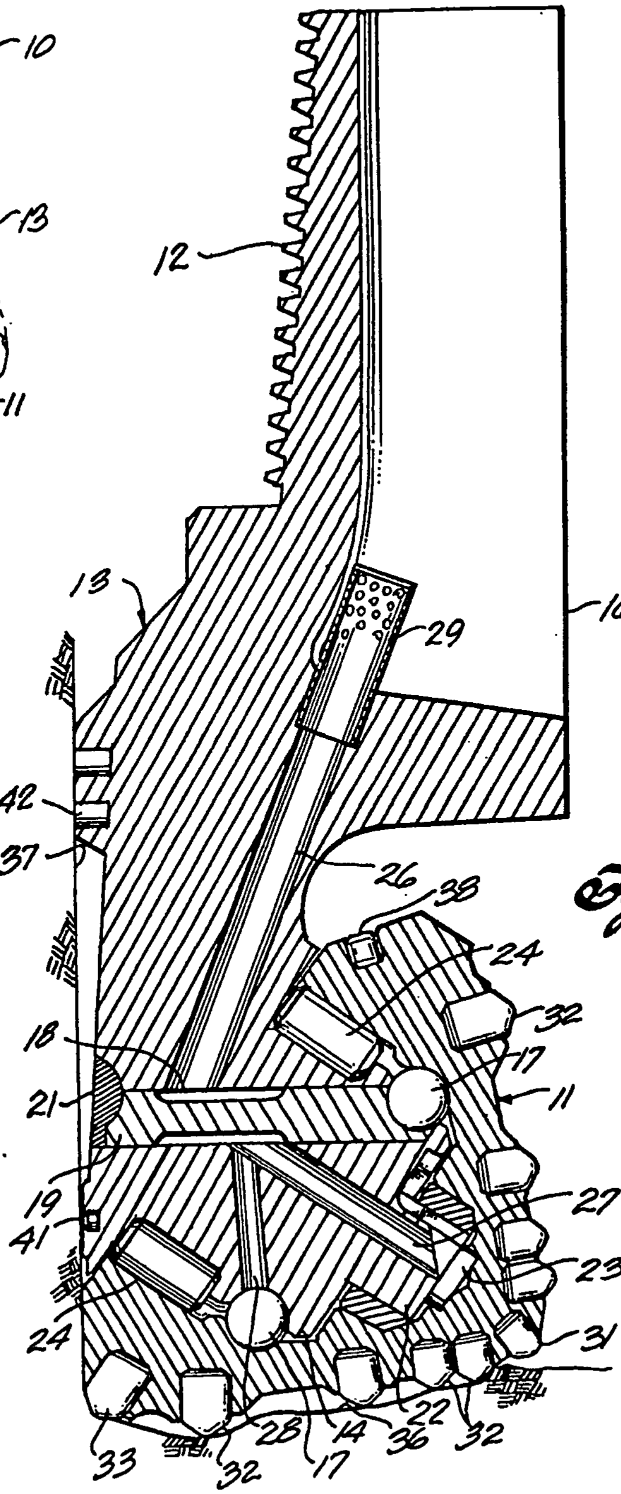


Fig. 2

BEST AVAILABLE COPY

SPECIFICATION

Rock bit and drilling method using same

This invention is concerned with an earth boring rock bit.

The use of rock bits with rolling cone cutters in drilling rock is a well-known and long-established art. A typical rock bit has a body on which are mounted three rolling cutters, each having a generally conical configuration, and each occupying much of a separate 120° sector above the bottom of the well bore. Each cone is equipped with a number of generally circular rows of inserts or cutting elements. Some cones have hardened steel teeth integral with the cone. The cones of concern in this application have tungsten carbide inserts forming the cutting elements. As the cone rotates, the work surface of the inserts of each row are applied sequentially in a circular path upon the bottom of the hole in the rock that is being drilled. As the rolling cone cutters roll on the bottom of the hole being drilled, the carbide inserts apply a high compressive load to the rock and fracture it. The cutting action in rolling cone cutters is typically by a combination of crushing and chipping.

In operation, a rolling cone drill bit is attached to the lower end of a drill stem or drill string, and rotated about the longitudinal axis of the drill bit on the bottom of a bore hole. Thus, the rolling cone cutters are caused to rotate, and as weight is applied to the bit by weight of the drill string or heavy drill collars, the tungsten carbide inserts of the cones crush, chip, gouge, and scrape the formation upon which the bit is rotated depending on the presence or absence of skew or offset of the cone axis from the axis of the bit. The particles of rock formation thus dislodged are carried out of the bore hole by drilling fluid such as drilling mud or air which is pumped downwardly through the drill string and rock bit, returning to the surface of the earth *via* the annular space between the drill string and the wall of the bore hole being drilled. The drilling fluid also conveys heat from the working surfaces and helps prevent overheating of the bit.

The tungsten carbide inserts along the periphery of a bit, that is, nearest the base of the cones, and which define the diameter of a hole being drilled are known as gage inserts. As the rolling cone cutters rotate, the gage inserts often scrape against rock at the periphery of the hole being drilled. These inserts also have the highest rate of application of loads because of their position at the outermost parts of the cones and bit.

Of all the inserts of a rolling cone cutter, the gage inserts are most susceptible to wear because they undergo both abrasion and compression as they scrape against the periphery of a bore hole. Any appreciable amount of wear on the gage inserts is undesirable because this could result in an undersized bore hole. When a replacement drill bit is inserted toward the bottom of an undersized bore hole, the replacement bit can pinch against the undersized portion of the hole and experience undue gage surface and bearing wear in reaming the undergage hole, thereby compounding the problem.

Excessive wear on gage inserts can occur even though the gage inserts are made of sintered tungsten carbide. The gage row inserts are subjected to compressive loads like the other inserts in the cone. They may also be subjected to abrasion by rubbing on the hole wall.

Tungsten carbide inserts on the gage row in a rolling cone cutter can exhibit poor wear resistance when drilling through formations containing steam or hot water containing corrosive salts such as when drilling for sources of geothermal energy.

Geothermal wells are often started using conventional oil well drilling techniques with a conventional rock bit and circulation of drilling mud as the drilling fluid. When high temperature regions are encountered, drilling operations are often changed to use air as the drilling fluid. At extremely high temperatures, stabilized foams can be added to the air for additional cooling and inhibition of corrosion. Drilling with air as the drilling fluid, coupled with the presence of hot water or steam, results in high fluid flow rates and it is believed that particle impingement in the high velocity fluids contributes to rapid wear of the gage inserts in a bit used for drilling geothermal wells.

Temperatures in geothermal wells range up to about 325°C and extremely corrosive conditions involving water, brine, hydrogen sulfide, and the like are often encountered. The temperatures to which the inserts in a rock bit are subjected are greater than the measured temperatures in the geothermal well because of friction as the inserts engage the rock being drilled. It is believed that surface temperatures of the inserts are several hundred degrees hotter than the measured temperatures in the well.

The unusual conditions in drilling geothermal wells is illustrated by drilling practice commonly used in the Geysers area in California. A practice has been adopted of drilling with a rock bit for about 15 to 20 hours and then pulling the drill string to replace the bit. Experience has shown that substantial wear of the gage row inserts is encountered in this short interval. By way of contrast, in drilling oil wells a comparable bit would have a useful life-time in the order of 100 hours or more. The types of rock encountered in geothermal wells are more difficult to drill than those in oil wells. Useful lives of 40 to 50 hours are more common in geothermal wells before the high temperature steam regions are reached.

The gage row of inserts tends to wear faster than other inserts on the bit, and thereby can be a limiting factor on the life of a drill bit. Excessive wear of the gage inserts can necessitate premature replacement of the drill bit. Replacement is a time-consuming and expensive process, especially in deep bore holes, since the entire drill string must be removed from the hole in

order to change the bit. Therefore, there is a need for a drill bit which has improved gage row inserts to avoid the drilling of undergage bore holes, particularly when the drill bit is used to drill for sources of geothermal energy.

The present invention is an earth boring rock bit comprising a rock bit body, at least one rolling cone cutter mounted on the bit body for rotation upon rotation of the bit body, and a plurality of sintered tungsten carbide inserts in recesses in such cutters, such tungsten carbide inserts being in a plurality of rows around such a cutter and including a gage row of gage inserts for drilling adjacent the peripheral wall of a hole being drilled, the tungsten carbide inserts in the gage row being a composite of primarily tungsten carbide particles having an average particle size greater than 0.5 microns sintered in a matrix of nickel, the nickel being in the range of from 6 to 20% by weight of the composite.

In some embodiments up to about 1/3 by weight of tantalum carbide can be substituted for a comparable portion of the tungsten carbide.

The present invention is also a method of drilling a geothermal well comprising rotating an earth boring rock bit as defined in the second last preceding paragraph on the bottom of a geothermal well being drilled.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings wherein:

Fig. 1 is a pictorial view of a rock bit having three rolling cone cutters mounted thereon in accordance with principles of this invention; and

Fig. 2 is a semi-schematic, longitudinal, cross-sectional view through one leg and rolling cone cutter of the rock bit of Fig. 1.

Fig. 1 is a pictorial view of a rock drill bit 10 having three conical rollers 11. Fig. 2 illustrates the mounting of one of the rollers 11. The conical roller 11 may also be referred to as a cone, a rolling cone cutter, or as a roller cutter. The bit has a heavy duty steel body with a threaded pin joint 12 at its upper end. The main body of the bit is formed by welding together three steel legs 13, each terminating in a conventional journal 14 on which the respective cutter cone 11 is mounted. Fig. 2 is a longitudinal cross section through one such leg. In use, the drill bit rotates about its longitudinal axis 16 with the cones at the lower end and the upper end connected to a drill string. As used herein, upper and lower refer to locations with respect to the position of a bit when drilling.

When the drill bit is assembled ball bearings 17 are added through a ball passage 18 from the exterior of the leg to a ball bearing race on the pin, which is then closed with a ball retainer 19 which retains the balls in place. Typically, the ball retainer is welded in place by a weld indicated at 21. The ball bearings 17 may carry some radial or thrust load between the journal and the cone, but a primary function of the balls is to retain the cone on the journal. A nose bearing 22 on the journal engages a thrust button 23 in the cone for carrying the principal thrust loads of the bearing structure. The brunt of the radial loads between the cone and journal is carried by the main bearing rollers 24.

The roller bearings, ball bearings and thrust bearings are cooled by air flowing through an air passage 26 from the interior of the bit body to the ball passage 18. Air flows from the ball passage 18 through an air passage 27 to the end of the nose 22. Slots in the bearing surfaces help distribute air for best cooling. Air is also directed to the ball bearings by way of an air passage 28 leading to the ball race. Air escapes from the cone past the roller bearings 24 thereby providing cooling of these surfaces as well. The inlet to the air passage 26 in the interior of the bit body is covered by a perforated metal tube 29 which serves to filter out particles which could damage the bearings surfaces.

Referring to Fig. 2, on the nose of the cone 11 there is mounted a single tungsten carbide insert 31. A plurality of inner rows of tungsten carbide inserts 32 are provided near the smaller end of the cone. Each rolling cone cutter also has an outermost row of carbide inserts 33, generally referred to as the gage row. The inserts in the outermost row are at the periphery of the hole being drilled and maintain its full gage. As the cone rolls during drilling, each gage insert 33 intermittently engages both the bottom 36 and the peripheral wall 37 of the bore hole formed by the drill bit in the rock formation being drilled. A circular row of heel inserts 38 is also provided on the heel of each cutter to provide abrasion resistance and help maintain gage of the rock bit. The heel inserts 38 can engage the wall of the hole being drilled although they are usually at a slightly smaller diameter than the gage inserts 33.

The tungsten carbide inserts are mounted in the cones in mounting recesses. The diameter of each tungsten carbide insert is typically larger than the diameter of the recess in which it is mounted. Each tungsten carbide insert is pressed into its recess and held in place by an interference fit between it and the steel wall of the recess.

The spacing of the inserts at the tip of the cone and within the rows 32, 33 and 38 on individual rolling cone cutters may be varied in a conventional manner to minimize tracking and maximize cutting efficiency. The inserts can also have a variety of conventional shapes to best drill various rock formations. Abrasion of the bit body when drilling geothermal wells can be a problem. Tungsten carbide inserts can therefore be provided on the peripheral portions on the bit body for minimizing such wear. A plurality of such inserts 41 are provided in recesses in the "shirt tail" portion of the rock bit body adjacent the hole wall. Another group of carbide inserts 42 are provided on the rock bit body nearer its upper end. The inserts 41 and 42 on the rock bit body are approximately at the gage of the hole being drilled. The upper inserts 42 serve to stabilize the bit in the hole and minimize wandering and other hole deviations. These inserts also serve as an indication that a hole is being drilled undersize.

Thus when the gage row 33 of inserts on the cones becomes worn to the point that the hole being drilled is less than the nominal gage diameter, the upper inserts 42 located on opposite parts of the bit body engage the hole wall and result in an increase in the torque required to turn the drill bit. Such increased torque can be sensed at the drill rig at the ground surface and drilling stopped before appreciable damage is done.

Tungsten carbide inserts for the cones of a rock bit are made by blending a mixture of particles of tungsten carbide and particles of a metal binder with a temporary binding agent such as wax. The thoroughly mixed and screened blend of powders is hydraulically pressed into a "green" compact which is heated, first to remove the wax, and eventually to sinter the compact. Heating in a vacuum or a reducing atmosphere to a temperature about 50°C below the melting point of the binder results in shrinkage of the compact and secure bonding of the tungsten carbide particles in the metallic binder phase. The sintered carbide insert is substantially at 100% of theoretical density of the carbide-matrix mixture. The microstructure of a sintered tungsten carbide insert has particles of tungsten carbide in a matrix of the binder metal. Some diffusion bonding of tungsten carbide particles may also occur.

A variety of sintered carbides have been developed for various purposes. A description of such carbides is contained in Volume 1 of *The Metals Handbook* at pages 659 to 668 (American Society for Metals, 1961). Sintered Tungsten carbide inserts for earth drilling are referred to at page 667.

Previously in rock bits straight tungsten carbide grades have been adopted for all of the carbide inserts on the cone. The average particle size of the tungsten carbide is from about two to seven microns. The binder phase is cobalt in the range of from about 6 to 16% by weight of the composite. It has been found that rock bits having such cobalt bonded tungsten carbide inserts in the gage row have limited useful life in drilling geothermal wells.

A rock bit provided in practice of this invention has tungsten carbide inserts in the gage row with nickel as the binder matrix. The amount of nickel in the composite is in the range of from about 3 to 20% by weight of the composite. If the nickel content is less than about 3% by weight the mean path through the nickel between carbide grains is so low that cracks can readily propagate and the composite is too brittle for practical application in a rock bit. When the nickel content is more than about 20% by weight, the composite is too soft and when subjected to extreme temperature and pressure conditions in a geothermal well, the insert may deform. Such a material also has low abrasion resistance and may be subject to extreme wear.

Preferably the nickel content of the composite is in the range of from about 6 to 16% by weight. When the nickel content is less than about 6%, the carbide inserts may be too brittle to be suitable for the heavy impact loads involved in rapid drilling. In some cases the nickel content can be less than about 6% if the tungsten carbide particle size is relatively large. If the nickel content is greater than about 16% by weight the insert can have excessive ductility and deform when subjected to the severe conditions in a geothermal well. The relatively large areas of nickel between tungsten carbide grains can also subject the resultant composite to undue abrasive wear.

The tungsten carbide particles in the composite are preferably in the range of from about 0.5 to 15 microns as determined by ASTM method B-390. If the tungsten carbide has an average particle size less than about 0.5 microns, the mean path through the nickel is too low to inhibit crack propagation, and the surface of the carbide is too large resulting in excessive brittleness of the composite. Preferably the tungsten carbide particles have an average size greater than about 1 micron. Particles smaller than about 1 micron can result in an insert that is too brittle for the impact loads involved in high speed drilling with a rock bit.

Large particle sizes are desirable in the tungsten carbide inserts. Average particle sizes up to about 10 microns are desirable. The present state-of-the-art limits the practical particle size for the tungsten carbide on high production rate inserts to less than about 10 microns. The larger particles are desirable since there is a relatively thicker web of nickel between the particles and a lower nickel content can therefore be used. The larger particles also provide a larger wear pad for the desired abrasion resistance in the gage of the geothermal rock bit.

It should be noted that tungsten carbide particles in the range of about 0.5 to 10 microns can be suitable for use in the heel row inserts 38 which are subjected to wear and very little impact loading.

A small amount of tantalum carbide can be substituted for an equivalent portion of the tungsten carbide in the composite material making up the rock bit inserts. The tantalum carbide is preferably present as less than about 1/3 by weight of the composite material. The tantalum carbide improves the high temperature resistance of the inserts but is a relatively expensive material. Increases in the tantalum carbide content above about 1/3 by weight do not appear to justify the additional cost. Preferably the tantalum carbide is present only up to about 10% by weight of the composite.

The particle size of the tantalum carbide is in about the same range as the particle size of the tungsten carbide for similar reasons. Preferably the tantalum carbide has a relatively smaller size than the tungsten carbide and is in the range of from about 1 to 3.5 microns. The effectiveness of tantalum carbide in resisting elevated temperatures is enhanced by having relatively small particles.

If desired up to about 0.5% of vanadium carbide can be included in the composition for inhibiting grain growth. Small amounts of

chromium carbide can be included for a similar purpose. Tantalum carbide also acts as a grain growth inhibitor and presence of such material negates any need for vanadium carbide or chromium carbide.

Small amounts of other hard metal carbides can be present in the tungsten carbide insert without significant detriment. Generally speaking addition of other carbides should be limited to avoid softening of the tungsten carbide insert. The other carbides are softer than tungsten carbide. Presence of some of the other high temperature metal carbides may result in significantly lower fracture toughness. Thus, for example, more than about 1% by weight of titanium carbide can have an adverse effect on fracture toughness. Somewhat larger amounts of molybdenum carbide, and columbium carbide can be tolerated. Small amounts of zirconium carbide and hafnium carbide can be tolerated.

In any case, the carbide inserts for the rock bit are primarily tungsten carbide bonded with nickel and may contain small amounts of other high melting metal carbides. Tantalum carbide may be present up to about 1/3 by weight for enhancing the high temperature resistance of the tungsten carbide inserts and inhibiting grain growth.

The nickel binder for the tungsten carbide particles can include small amounts of other metals such as cobalt, iron, chromium or molybdenum. It is desirable that such other metals be present as less than about 1/5 by weight of the binder. Chromium can be desirable in the binder for enhancing corrosion resistance. As used herein the terms nickel binder, nickel matrix and the like refer to a composition which can contain such small amounts of other metals.

Nickel binder in tungsten carbide compositions for some applications have been proposed. As pointed out by Paul Schwarzkopf and Richard Kieffer in *Cemented Carbides* (1960) at page 188, "Early attempts to replace Co as binder metal by iron, nickel, or alloys of . . . failed to indicate any special technical advantages."

Preferably the gage row of inserts in a rock bit is formed of a nickel bonded tungsten carbide as hereinabove described. The gage row inserts are subjected to the most severe abrasion conditions and are therefore most susceptible to wear. Undue wear of the gage row inserts can result in an undersized hole with consequent problems. Thus, significant wear of the gage row inserts can result in premature need for changing a bit when other inserts are still capable of additional drilling. Wear of inserts in the inner rows can reduce the rate of drilling but do not affect the gage of the hole. It is, therefore, preferred that the inserts on the gage row be nickel bonded tungsten carbide as hereinabove described. The inner rows of inserts can be conventional cobalt bonded tungsten carbide.

It is desirable that the heel row of inserts in a rock bit be nickel bonded tungsten carbide as hereinabove described. Preferably the heel row inserts have a relatively small carbide particle size. The heel row inserts help limit undue wear of the cutter cones and help maintain the gage of the hole being drilled. The heel inserts are subjected to considerable abrasion and wear. Nickel bonded tungsten carbide can significantly improve the effective lifetime of the heel inserts.

If desired, the inserts in the inner rows on the cutter cones can also be nickel bonded tungsten carbide as hereinabove described. Such an arrangement can be desirable where the improved performance of the gage row inserts makes the inner rows of inserts the limiting factor on the lifetime of a rock bit. Use of nickel bonded inserts can also minimize possibilities of confusion during assembly of the cones.

As one example of application of this development a rock bit having a gage diameter of 8 and 5/8 inch was made with nickel bonded tungsten carbide inserts in the gage row. The inserts had 10% by weight of nickel, 10% by weight of tantalum carbide with an average particle size of about 2.6 microns, and a balance of tungsten carbide with a particle size of about 3 microns. The inserts in the inner rows on the cones were conventional cobalt bonded tungsten carbide inserts.

The rock bit was run in a geothermal well under substantially the same conditions that a conventional bit having all cobalt bonded tungsten carbide inserts would have been run. The bit was pulled from the hole after about sixteen hours of running on the hole bottom and examined for wear. Surprisingly the nickel bonded tungsten carbide inserts in the gage row showed no more wear than would be expected of cobalt bonded tungsten carbide inserts in the same location. This was unexpected since nickel bonded tungsten carbide is regarded as significantly inferior to cobalt bonded tungsten carbide for inserts in rock bits. Hardness, wear resistance and transverse rupture strength of nickel bonded carbide inserts are generally lower than cobalt bonded tungsten carbide inserts. The nickel bonded tungsten carbide inserts showed no evidence of corrosive attack by the high temperature, corrosive gases in the geothermal well. Cobalt bonded tungsten carbide inserts under the same conditions show appreciable corrosive attack.

CLAIMS

1. An earth boring rock bit comprising a rock bit body, at least one rolling cone cutter mounted on the bit body for rotation upon rotation of the bit body, and a plurality of sintered tungsten carbide inserts in recesses in such cutters, such tungsten carbide inserts being in a plurality of rows around such a cutter and including a gage row of gage inserts for drilling adjacent the peripheral wall of a hole being drilled, the tungsten carbide inserts in the gage row being a composite of primarily tungsten carbide particles having an average particle size greater than 0.5 microns sintered in a matrix of nickel, the nickel being in the range of from 6 to 20% by weight of the composite.

2. A rock bit as claimed in claim 1, wherein the

gage row inserts have a nickel matrix in the range of from 6 to 16% by weight of the composite.

3. A rock bit as claimed in claim 1 or claim 2, wherein the gage row inserts are a composite wherein the tungsten carbide particles have an average particle size in the range of from 1 to 15 microns.

4. A rock bit as claimed in any preceding claim, wherein the gage row inserts are a composite wherein the tungsten carbide particles have an average particle size in the range of from 1 to 10 microns.

5. A rock bit as claimed in any preceding claim, wherein the gage row inserts are a composite including up to about 1/3 by weight of tantalum carbide.

6. A rock bit as claimed in any preceding claim, further comprising a heel row of tungsten carbide inserts in a portion of the cutter adjacent the wall of a hole being drilled, such heel inserts being a composite of primarily tungsten carbide particles having an average particle size in the range of from 0.5 to 10 microns sintered in a matrix of nickel in the range of from 3 to 20% by weight of the composite.

7. A rock bit as claimed in any preceding claim, wherein such tungsten carbide inserts in inner rows nearer the axis of the rock bit than the gage row of inserts are a composite of primarily tungsten carbide particles having an average particle size in the range of from about 0.5 to 15 microns sintered in a matrix of nickel in the range of from about 3 to 20% by weight of the composite.

8. A rock bit as claimed in any of claims 1 to 6, wherein such tungsten carbide inserts in inner rows nearer the axis of the rock bit than the gage row of inserts are a composite of primarily tungsten carbide particles having an average particle size in the range of from 1 to 10 microns sintered in a matrix of cobalt in the range of from 3 to 20% by weight of the composite.

9. A method of drilling a geothermal well comprising rotating an earth boring rock bit as claimed in any of claims 1 to 8 on the bottom of a geothermal well being drilled.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1981. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.